**Document 7**

# AIRBORNE LIDAR FOR PACIFIC SARDINE SURVEYS

Prepared for
*WORKSHOP ON ENHANCING STOCK ASSESSMENTS OF PACIFIC SARDINE IN THE CALIFORNIA CURRENT THROUGH COOPERATIVE SURVEYS*
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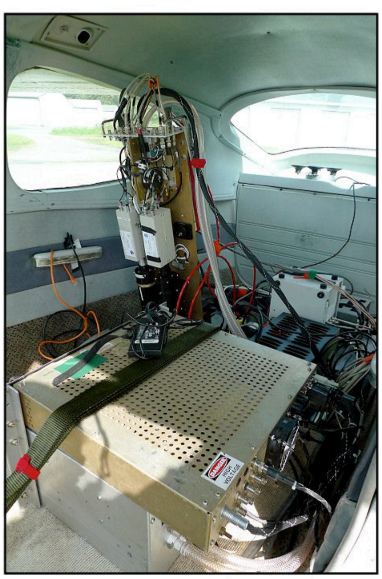
## I. Introduction and Background of Survey Method

### *1. Theoretical basis and assumptions (concept, absolute biomass, abundance index; conditions under which method works)*

The National Oceanic and Atmospheric Administration (NOAA) are developing airborne lidar for fisheries research and management. Lidar, an acronym for Light Detection and Ranging, is similar to radar or sonar, but the source is a short pulse of laser light. In the NOAA Fish Lidar, the configuration is very similar to a single-beam echo sounder. It doesn't scan, but samples along a narrow line along the path of the platform.

The lidar concept is simple. A short pulse of laser light is transmitted downward from the aircraft as it flies along the track. As the pulse travels through the water, a portion is scattered back toward the aircraft, where it is collected by a telescope, converted into an electronic signal, and recorded on a computer. The time of the return of a particular signal is directly related to its depth and the strength is related to the optical reflectivity at that depth.



The NOAA Fish Lidar has flown on a number of light aircraft, and is fairly easy to install on others. The aircraft include the Twin Otter, Aero Commander, King Air 90, Partenavia Observer, and Cessna Cardinal. Figure 1 is a photo of the lidar installed in the rear of the Cardinal. The requirements are a port in the bottom of the aircraft and enough electrical power. At full power, the system requires 1 kW, but can operate at less than a third of this with some reduction in performance.

*Fig. 1. Photo of NOAA Fish Lidar in rear compartment of a Cessna 177.*

The interpretation of the lidar signal is a bit complicated, since light reflects from everything in the water, including suspended sediments, plankton, and fish. Separating the sardine signal from that of these other objects will require processing of the return signal. Processing techniques have been developed, and lidar results compare well with more traditional survey techniques as long as the time difference between the surveys is less than about four days. Details of the instrument, data analysis, and comparative studies are provided in the references.

***2. Objectives of application (what stock assessment input does method produce*)**

The eventual objective of Fish Lidar would be a biomass estimate, but this cannot be done reliably yet. There are issues of instrument calibration, target strength relationships, and shadowing in dense schools that remain objects of active research. Currently, the information that can be produced reliably includes number of schools, school area, and integrated optical backscatter at specified depth and horizontal resolutions.

Lidar target strength measurements have been made for sardines caught in the Southern California Bight. These were done with live fish in a tank at Scripps Institution of Oceanography. This provided an estimate for this particular collection of fish, but a target strength – length relationship like those used in acoustics has not been done.

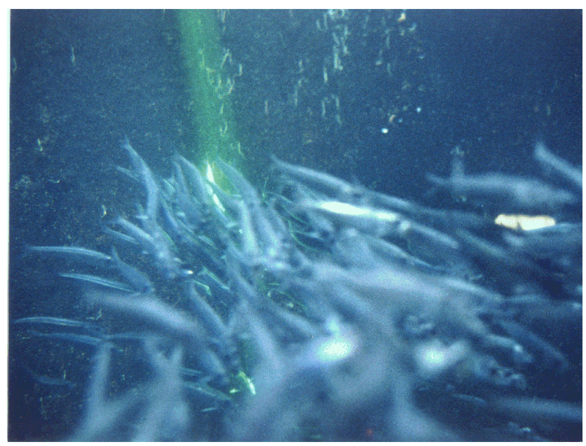


*Fig. 2. Photo of lidar beam through school of sardines during calibration experiment.*

One application that has been tested for sardines against a ship survey in the Pacific Northwest is that of using the lidar to direct an adaptive ship survey. The ship performed its full survey lines and the lidar was flown over the same lines on the same day. We considered what the acoustic survey performance would have been if the lidar were used only to locate areas (typically the offshore ends of transects) where no sardines were present. In this type of survey, the cost savings and performance depend on the criteria used for adaptive sampling. For example, 89% of the total acoustic energy would have been recovered by sampling only 64% of the total survey area using one criterion to direct the ship. Under a more restrictive criterion, 70% of the total would have been recovered by sampling only 28% of the total area. This represents a significant cost savings.

***3. Pros and Cons of method (advantages and disadvantages)***

There are several advantages of aerial techniques over those based on surface vessels. One is platform cost. While costs vary considerably, the hourly rate for research aircraft and research ships are comparable. The survey speed of the aircraft is 10 – 20 times that of the ship, however, so the cost per mile surveyed is considerably less. Another advantage is that fish do not avoid aircraft. Also, they do not move very far during an aerial survey. The latter characteristic means that a more synoptic view of the fish distribution is produced.

The main disadvantages to lidar are common to all remote techniques. These include difficulties with target identification and robust relationships to convert a measured signal into a biomass estimate.

One specific disadvantage of the lidar is the limited depth penetration. The best that has been obtained is about 50 m. In highly productive coastal waters, 20 – 30 m is more common. In very turbid inland water, the penetration can be as little as ten m.

One disadvantage of the non-scanning lidar for some applications is the narrow swath width (5 m). The effects of this on performance were modeled for surveys of sardines and anchovies. The results of this modeling suggested that this was not a significant limitation. The chance of detection a sardine school group depends on the swath wide of the lidar if that width is much greater than the diameter of the school group. However, the chance of detection a school group will depend on the width of the school group if it is more than the swath width. This is typically the case for sardines, so the narrow swath width of the lidar does not limit the chance of detecting a school group.

Lidar has also been quantitatively compared with imaging techniques for the case of menhaden surveys in Chesapeake Bay. The results showed that video detected more schools because of the wider swath width, but lidar detected schools to greater depth. Lidar had fewer false identifications, fewer missed schools, and less variability in repeated surveys of the same area.

## II. Design for Survey in the CA Current (current design and potential design enhancements)

### *1. Spatial Coverage (current and potential; also include who currently conducts each survey and level of synopticity)*

There are currently no operational lidar surveys. Because of the speed of the aircraft, the potential spatial coverage and level of synopticity are almost unlimited.

### *2. Temporal Coverage (seasonal - current and potential)*

Reinstalling the lidar in an aircraft in which it has already been operated typically takes about four hours. This implies that the potential temporal coverage can be high. One limitation is weather. High winds and rain are not a limitation, but the system cannot operate in fog or low (below flight altitude) clouds. This may delay surveys in some areas at some times of the year.

***3. Statistical sampling protocols (including evaluation of sample size requirements)***

The lidar produces profiles along the flight track, so the sampling protocols that have been developed for line transects apply.

***4. Data collection and treatment***

The data are stored on a hard disk during the flight to be processed later. School identification is most reliably done manually, although automated identification is a topic of active research. Often, a coincident video record of the surface is used to reduce false identifications.

***5. Analytical procedure (including variance estimations)***

Analysis of the lidar data for schools is most reliably done by visual inspection. Automated techniques have been used for integrated echo strength. These involve spatial filtering of the data and application of a threshold to remove return from plankton. Previous work has shown that these techniques work well, but need to be adapted to local conditions – the same filter length and threshold value will not work for all species of fish at all locations. The best performance is obtained with well-defined schools in clear water.

## III. Lessons Learned from Application

1. Method conditions met? (biological, ecological, oceanography)
   See I.3.
2. Operational conditions met? (staffing, funding, time series)
   See I.3.
3. Past peer-review advice for improvement (e.g. STAR)
   not applicable

## IV. Workshop Recommendations for Surveys to Enhance Stock Assessments

1. Opportunities for collaboration
   TBD (Discussion)
2. Linkage to other methods

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